CHAPTER 24 (Odd)

1. a. **positive-going** b. V_b = **2 V** c. t_p = **0.2 ms**

   d. Amplitude = 8 V − 2 V = **6 V**

   e. $\% \text{ tilt} = \dfrac{V_1 - V_2}{V} \times 100\%$

   $V = \dfrac{8\text{ V} + 7.5\text{ V}}{2} = 7.75\text{ V}$

   $\% \text{ tilt} = \dfrac{8\text{ V} - 7.5\text{ V}}{7.75\text{ V}} \times 100\% = \mathbf{6.5\%}$

3. a. **positive-going** b. V_b = **10 mV** c. $t_p = \left[\dfrac{8}{10}\right] 4\text{ ms} = \mathbf{3.2\text{ ms}}$

   d. Amplitude = (30 − 10)mV = **20 mV**

   e. $\% \text{ tilt} = \dfrac{V_1 - V_2}{V} \times 100\%$

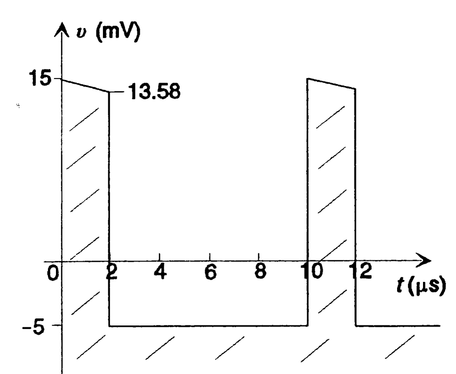
   $V = \dfrac{30\text{ mV} + 28\text{ mV}}{2} = 29\text{ mV}$

   $\% \text{ tilt} = \dfrac{30\text{ mV} - 28\text{ mV}}{29\text{ mV}} \times 100\% \cong \mathbf{6.9\%}$

5. $\text{tilt} = \dfrac{V_1 - V_2}{V} = 0.1$ with $V = \dfrac{V_1 + V_2}{2}$

   Substituting V into top equation,

   $\dfrac{V_1 - V_2}{\dfrac{V_1 + V_2}{2}} = 0.1$ leading to $V_2 = \dfrac{0.95\ V_1}{1.05}$ or $V_2 = 0.905(15\text{ mV}) = 13.58\text{ mV}$



7. a. $T = (4.8 - 2.4)\text{div.}[50\ \mu\text{s/div.}] = \mathbf{120\ \mu s}$ b. $f = \dfrac{1}{T} = \dfrac{1}{120\ \mu\text{s}} = 8.33\text{ kHz}$

c. Maximum Amplitude: (2.2 div.)(0.2 V/div.) = 0.44 V = **440 mV**
Minimum Amplitude: (0.4 div.)(0.2 V/div.) = 0.08 V = **80 mV**

9. $T = (15 - 7)\mu s = 8\ \mu s$

$$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu s} = \mathbf{125\ kHz}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{(20 - 15)\mu s}{8\ \mu s} \times 100\% = \frac{5}{8} \times 100\% = \mathbf{62.5\%}$$

11. a. $T = (9 - 1)\mu s = \mathbf{8\ \mu s}$ b. $t_p = (3 - 1)\mu s = \mathbf{2\ \mu s}$

c. $$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu s} = \mathbf{125\ kHz}$$

d. V_{av} = (Duty cycle)(Peak value) + (1 − Duty cycle)(V_b)

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{2\ \mu s}{8\ \mu s} = \times 100\% = 25\%$$

$$V_{av} = (0.25)(6\text{ mV}) + (1 - 0.25)(-2\text{ mV}\}$$
$$= 1.5\text{ mV} - 1.5\text{ mV} = \mathbf{0\ V}$$

or

$$V_{av} = \frac{(2\ \mu s)(6\text{ mV}) - (2\ \mu s)(6\text{ mV})}{8\ \mu s} = \mathbf{0\ V}$$

e. $$V_{eff} = \sqrt{\frac{(36 \times 10^{-6})(2\ \mu s) + (4 \times 10^{-6})(6\ \mu s)}{8\ \mu s}} = \mathbf{3.464\ mV}$$

13. Ignoring tilt and using 20 mV level to define t_p

t_p = (2.8 div. − 1.2 div.)(2 ms/div.) = 3.2 ms
T = (at 10 mV level) = (4.6 div. − 1 div.)(2 ms/div.) = 7.2 ms

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{3.2\text{ ms}}{7.2\text{ ms}} \times 100\% = 44.4\%$$

V_{av} = (Duty cycle)(peak value) + (1 − Duty cycle)(V_b)
= (0.444)(30 mV) + (1 − 0.444)(10 mV)
= 13.320 mV + 5.560 mV
= **18.88 mV**

15. Using methods of Section 13.8:

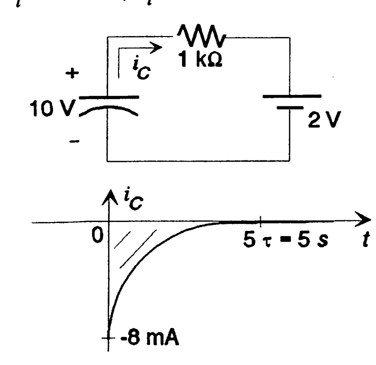
$A_1 = b_1h_1$ = [(0.2 div.)(50 μs/div.)][(2 div.)(0.2 V/div.)] = 4 μsV
$A_2 = b_2h_2$ = [(0.2 div.)(50 μs/div.)][(2.2 div.)(0.2 V/div.)] = 4.4 μsV
$A_3 = b_3h_3$ = [(0.2 div.)(50 μs/div.)][(1.4 div.)(0.2 V/div.)] = 2.8 μsV
$A_4 = b_4h_4$ = [(0.2 div.)(50 μs/div.)][(1 div.)(0.2 V/div.)] = 2.0 μsV
$A_5 = b_5h_5$ = [(0.2 div.)(50 μs/div.)][(0.4 div.)(0.2 V/div.)] = 0.8 μsV

$$V_{av} = \frac{(4 + 4.4 + 2.8 + 2.0 + 0.8)\mu sV}{120\ \mu s} = \mathbf{117\ mV}$$

17. $v_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$
$= 8 + (4 - 8)(1 - e^{-t/20\text{ ms}})$
$= 8 - 4(1 - e^{-t/20\text{ ms}})$
$= 8 - 4 + 4e^{-t/20\text{ ms}}$
$= 4 + 4e^{-t/20\text{ ms}}$
$\mathbf{v_C = 4(1 + e^{-t/20\text{ ms}})}$

$\tau = RC = (2\text{ k}\Omega)(10\ \mu\text{F})$
$= 20\text{ ms}$

19. $V_i = 10\text{ V}, I_i = 0\text{ A}$

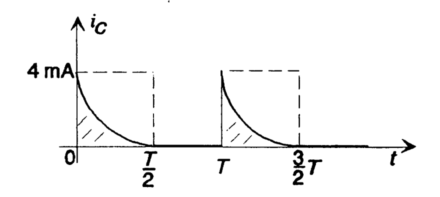


Using the defined direction of i_C

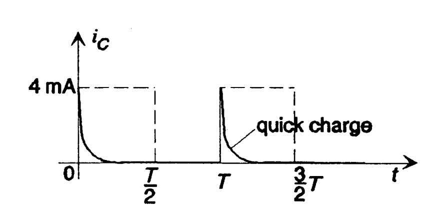
$$i_C = \frac{-(10\text{ V} - 2\text{ V})}{1\text{ k}\Omega}e^{-t/\tau}$$
$$\tau = RC = (1\text{ k}\Omega)(1000\ \mu\text{F}) = 1\text{ s}$$
$$i_C = -\frac{8\text{ V}}{1\text{ k}\Omega}e^{-t}$$
and $\mathbf{i_C = -8 \times 10^{-3}e^{-t}}$

21. The mathematical expression for i_C is the same for each frequency!
$\tau = RC = (5\text{ k}\Omega)(0.04\ \mu\text{F}) = 0.2\text{ ms}$
and $i_C = \dfrac{20\text{ V}}{5\text{ k}\Omega}e^{-t/0.2\text{ ms}} = 4 \times 10^{-3}e^{-t/0.2\text{ ms}}$

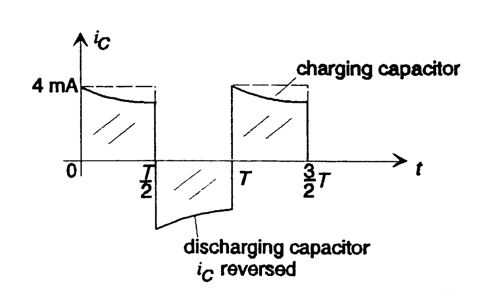
a. $T = \dfrac{1}{500\text{ Hz}} = 2\text{ ms}, \dfrac{T}{2} = 1\text{ ms}$
$5\tau = 5(0.2\text{ ms}) = 1\text{ ms} = \dfrac{T}{2}$



b. $T = \dfrac{1}{100\text{ Hz}} = 10\text{ ms}, \dfrac{T}{2} = 5\text{ ms}$
$5\tau = 1\text{ ms} = \dfrac{1}{5}\left[\dfrac{T}{2}\right]$



c. $T = \dfrac{1}{5000\text{ Hz}} = 0.2\text{ ms}, \dfrac{T}{2} = 0.1\text{ ms}$
$5\tau = 1\text{ ms} = 10\left[\dfrac{T}{2}\right]$



23. $v_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$

$V_i = 20\text{ V},\ V_f = 20\text{ V}$

$v_C = 20 + (20 - 20)(1 - e^{-t/RC})$

$= 20\text{ V (for } 0 \rightarrow \frac{T}{2})$

For $\frac{T}{2} \rightarrow T$, $v_i = 0$ V and $v_C = 20e^{-t/\tau}$

$\tau = RC = 0.2$ ms

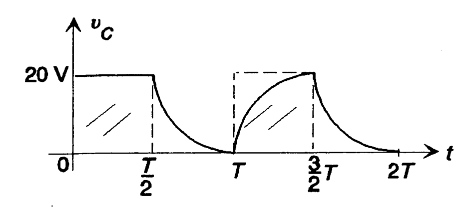
with $\frac{T}{2} = 1$ ms and $5\tau = \frac{T}{2}$

For $T \rightarrow \frac{3}{2}T$, $v_i = 20$ V

$v_C = 20(1 - e^{-t/\tau})$

For $\frac{3}{2}T \rightarrow 2T$, $v_i = 0$ V

$v_C = 20e^{-t/\tau}$



25. $\mathbf{Z}_p$: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10\text{ kHz})(3\text{ pF})} = 5.31\text{ M}\Omega$

$\mathbf{Z}_p = \dfrac{(9\text{ M}\Omega\ \angle 0°)(5.31\text{ M}\Omega\ \angle -90°)}{9\text{ M}\Omega - j5.31\text{ M}\Omega} = 4.573\text{ M}\Omega\ \angle -59.5°$

$\mathbf{Z}_s$: $C_T = 18\text{ pF} + 9\text{ pF} = 27\text{ pF}$

$X_C = \dfrac{1}{2\pi fC_T} = \dfrac{1}{2\pi(10\text{ kHz})(27\text{ pF})} = 0.589\text{ M}\Omega$

$\mathbf{Z}_s = \dfrac{(1\text{ M}\Omega\ \angle 0°)(0.589\text{ M}\Omega\ \angle -90°)}{1\text{ M}\Omega - j0.589\text{ M}\Omega} = 0.507\text{ M}\Omega\ \angle -59.5°$

$$\mathbf{V}_{\text{scope}} = \frac{\mathbf{Z}_s\mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.507\text{ M}\Omega\ \angle -59.5°)(100\text{ V}\angle 0°)}{(0.257\text{ M}\Omega - j0.437\text{ M}\Omega) + (2.324\text{ M}\Omega - j3.939\text{ M}\Omega)}$$

$$= \frac{50.7 \times 10^6\text{ V}\ \angle -59.5°}{5.07 \times 10^6\ \angle -59.5°} = \mathbf{10\ V\ \angle 0°} = \frac{1}{10}(100\text{ V}\ \angle 0°)$$

$\theta_{\mathbf{Z}_s} = \theta_{\mathbf{Z}_p} = \mathbf{-59.5°}$

Chapter 24 (Even)

2. a. **negative-going** b. **+7 mV** c. **3 μs**

d. **−8 mV** (from base line level)

e. $V = \dfrac{-8\text{ mV} - 7\text{ mV}}{2} = \dfrac{-15\text{ mV}}{2} = -7.5\text{ mV}$

$\%\text{ Tilt} = \dfrac{V_1 - V_2}{V} \times 100\% = \dfrac{-8\text{ mV} - (-7\text{ mV})}{-7.5\text{ mV}} \times 100\%$

$= \dfrac{-1\text{ mV}}{-7.5\text{ mV}} \times 100\% = \mathbf{13.3\%}$

f. $T = 15\ \mu\text{s} - 7\ \mu\text{s} = 8\ \mu\text{s}$

$\text{prf} = \dfrac{1}{T} = \dfrac{1}{8\ \mu s} = \mathbf{125\ kHz}$

g. $\text{Duty cycle} = \dfrac{t_p}{T} \times 100\% = \dfrac{3\ \mu s}{8\ \mu s} \times 100\% = \mathbf{37.5\%}$

4. $t_r \cong (0.2\text{ div.})(2\text{ ms/div.}) = \mathbf{0.4\ ms}$
$t_f \cong (0.4\text{ div.})(2\text{ ms/div.}) = \mathbf{0.8\ ms}$

6. a. $t_r = 80\%$ of straight line segment
$= 0.8(2\ \mu\text{s}) = \mathbf{1.6\ \mu s}$

b. $t_f = 80\%$ of 4 μs interval
$= 0.8(4\ \mu\text{s}) = \mathbf{3.2\ \mu s}$

c. At 50% level (10 mV)
$t_p = (8 - 1)\mu\text{s} = \mathbf{7\ \mu s}$

d. $\text{prf} = \dfrac{1}{T} = \dfrac{1}{20\ \mu s} = \mathbf{50\ kHz}$

8. $T = (3.6 - 2.0)\text{ms} = 1.6\text{ ms}$

$\text{prf} = \dfrac{1}{T} = \dfrac{1}{1.6\text{ ms}} = \mathbf{625\ Hz}$

$\text{Duty cycle} = \dfrac{t_p}{T} \times 100\% = \dfrac{0.2\text{ ms}}{1.6\text{ ms}} \times 100\% = \mathbf{12.5\%}$

10. $T = (3.6\text{ div.})(2\text{ ms/div.}) = 7.2\text{ ms}$

$\text{prf} = \dfrac{1}{T} = \dfrac{1}{7.2\text{ ms}} = \mathbf{138.89\ Hz}$

$\text{Duty cycle} = \dfrac{t_p}{T} \times 100\% = \dfrac{1.6\text{ div.}}{3.6\text{ div.}} \times 100\% = \mathbf{44.4\%}$

12. Eq. 24.5 cannot be applied due to tilt in the waveform.
(Method of Section 13.6)
Between 2 and 3.6 ms

$$V_{av} = \frac{(3.4\text{ ms} - 2\text{ ms})(2\text{ V}) + (3.6\text{ ms} - 3.4\text{ ms})(7.5\text{ V}) + \frac{1}{2}(3.6\text{ ms} - 3.4\text{ ms})(0.5\text{ V})}{3.6\text{ ms} - 2\text{ ms}}$$

$$= \frac{(1.4\text{ ms})(2\text{ V}) + (0.2\text{ ms})(7.5\text{ V}) + \frac{1}{2}(0.2\text{ ms})(0.5\text{ V})}{1.6\text{ ms}}$$

$$= \frac{2.8\text{ V} + 1.5\text{ V} + 0.05\text{ V}}{1.6} = \mathbf{2.719\text{ V}}$$

14. V_{av} = (Duty cycle)(Peak value) + (1 − Duty cycle)(V_b)

Duty cycle $= \frac{t_p}{T}$ (decimal form)

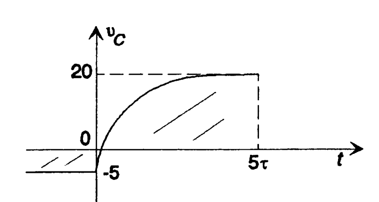
$= \frac{(8 - 1)\mu s}{20\ \mu s} = 0.35$

$V_{av} = (0.35)(20\text{ mV}) + (1 - 0.35)(0)$
$= 7\text{ mV} + 0$
$= \mathbf{7\text{ mV}}$

16. Using the defined polarity of Fig. 24.57 for v_C, $V_i = -5$ V, $V_f = +20$ V and $\tau = RC = (10\text{ k}\Omega)(0.02\ \mu\text{F}) = 0.2$ ms

a. $v_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$
$= -5 + (20 - (-5))(1 - e^{-t/0.2\text{ ms}})$
$= -5 + 25(1 - e^{-t/0.2\text{ ms}})$
$= -5 + 25 - 25e^{-t/0.2\text{ ms}}$
$v_C = \mathbf{20 - 25e^{-t/0.2\text{ ms}}}$

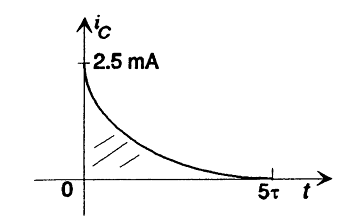
b.



c. $I_i = 0$

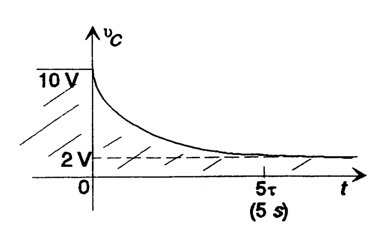
$$i_C = \frac{E - v_C}{R} = \frac{20\text{ V} - [20\text{ V} - 25\text{ V}e^{-t/0.2\text{ ms}}]}{10\text{ k}\Omega} = \mathbf{2.5 \times 10^{-3}e^{-t/0.2\text{ ms}}}$$

d.



18. $V_i = 10\text{ V},\ V_f = 2\text{ V},\ \tau = RC = (1\text{ k}\Omega)(1000\ \mu\text{F}) = 1\text{ s}$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= 10\text{ V} + (2\text{ V} - 10\text{ V})(1 - e^{-t}) \\ &= 10 - 8(1 - e^{-t}) \\ &= 10 - 8 + 8e^{-t} \\ v_C &= \mathbf{2 + 8e^{-t}} \end{aligned}$$



20. $\tau = RC = (5\text{ k}\Omega)(0.04\ \mu\text{F}) = 0.2\text{ ms}$ (throughout)

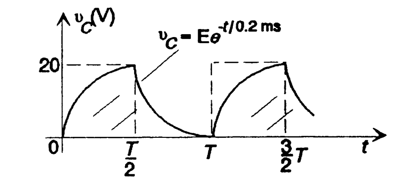
$v_C = E(1 - e^{-t/\tau}) = 20(1 - e^{-t/0.2\text{ ms}})$

(Starting at $t = 0$ for each plot)

a. $T = \dfrac{1}{f} = \dfrac{1}{500\text{ Hz}} = 2\text{ ms}$

$\dfrac{T}{2} = 1\text{ ms}$

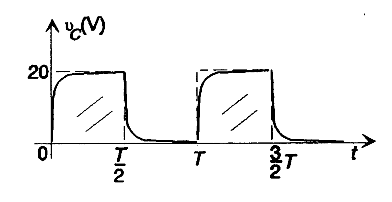
$5\tau = 1\text{ ms} = \dfrac{T}{2}$

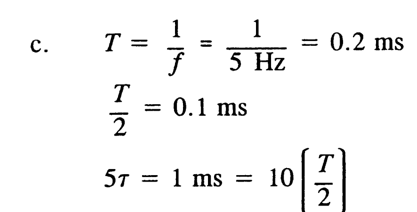


b. $T = \dfrac{1}{f} = \dfrac{1}{100\text{ Hz}} = 10\text{ ms}$

$\dfrac{T}{2} = 5\text{ ms}$

$5\tau = 1\text{ ms} = \dfrac{1}{5}\left[\dfrac{T}{2}\right]$

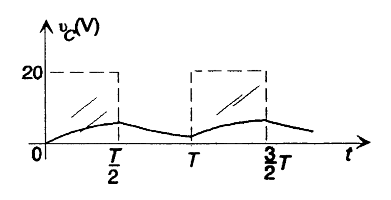


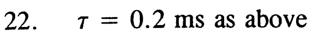


c. $T = \dfrac{1}{f} = \dfrac{1}{5\text{ Hz}} = 0.2\text{ ms}$

$\dfrac{T}{2} = 0.1\text{ ms}$

$5\tau = 1\text{ ms} = 10\left[\dfrac{T}{2}\right]$





22. $\tau = 0.2\text{ ms}$ as above

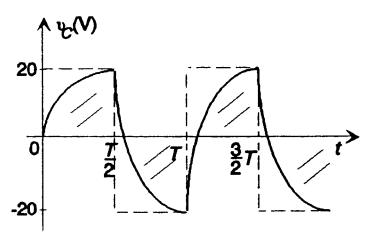
$T = \dfrac{1}{500\text{ Hz}} = 2\text{ ms}$

$5\tau = 1\text{ ms} = \dfrac{T}{2}$

$0 \rightarrow \dfrac{T}{2}$: $v_C = 20(1 - e^{-t/0.2\text{ ms}})$

$\dfrac{T}{2} \rightarrow T$: $V_i = 20\text{ V},\ V_f = -20\text{ V}$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= 20 + (-20 - 20)(1 - e^{-t/0.2\text{ ms}}) \\ &= 20 - 40(1 - e^{-t/0.2\text{ ms}}) \\ &= 20 - 40 + 40e^{-t/0.2\text{ ms}} \\ v_C &= \mathbf{-20 + 40e^{-t/0.2\text{ ms}}} \end{aligned}$$



$$T \rightarrow \frac{3}{2}T: \quad V_i = -20 \text{ V}, \ V_f = +20 \text{ V}$$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= -20 + (20 - (-20))(1 - e^{-t/\tau}) \\ &= -20 + 40(1 - e^{-t/\tau}) \\ &= -20 + 40 - 40e^{-t/\tau} \\ v_C &= \mathbf{20 - 40}e^{-t/0.2 \text{ ms}} \end{aligned}$$

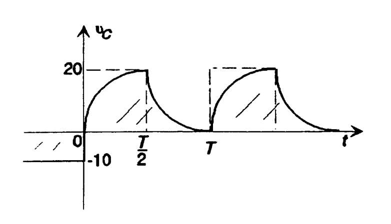
24. $\tau = RC = 0.2$ ms

$$5\tau = 1 \text{ ms} = \frac{T}{2}$$

$$V_i = -10 \text{ V}, \ V_f = +20 \text{ V}$$

$$0 \rightarrow \frac{T}{2}:$$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= -10 + (20 - (-10))(1 - e^{-t/\tau}) \\ &= -10 + 30(1 - e^{-t/\tau}) \\ &= -10 + 30 - 30e^{-t/\tau} \\ v_C &= \mathbf{+20 - 30}e^{-t/0.2 \text{ ms}} \end{aligned}$$



$$\frac{T}{2} \rightarrow T: \quad V_i = 20 \text{ V}, \ V_f = 0 \text{ V}$$

$$v_C = \mathbf{20}e^{-t/0.2 \text{ ms}}$$

26. $\mathbf{Z}_p$: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^5 \text{ rad/s})(3 \text{ pF})} = 3.333 \text{ M}\Omega$

$$\mathbf{Z}_p = \frac{(9 \text{ M}\Omega \angle 0°)(3.333 \text{ M}\Omega)}{9 \text{ M}\Omega - j3.333 \text{ M}\Omega} = 3.126 \text{ M}\Omega \angle -69.68°$$

$\mathbf{Z}_s$: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^5 \text{ rad/s})(27 \text{ pF})} = 0.370 \text{ M}\Omega$

$$\mathbf{Z}_s = \frac{(1 \text{ M}\Omega \angle 0°)(0.370 \text{ M}\Omega \angle -90°)}{1 \text{ M}\Omega - j0.370 \text{ M}\Omega} = 0.347 \text{ M}\Omega \angle -69.68°$$

✓ $\theta_{\mathbf{Z}_p} = \theta_{\mathbf{Z}_s}$

$$\mathbf{V}_{\text{scope}} = \frac{\mathbf{Z}_s \mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.347 \text{ M}\Omega \angle -69.68°)(100 \text{ V} \angle 0°)}{(0.121 \text{ M}\Omega - j0.325 \text{ M}\Omega) + (1.086 \text{ M}\Omega - j2.931 \text{ M}\Omega)}$$

$$= \frac{34.70 \times 10^6 \text{ V} \angle -69.68°}{3.470 \times 10^6 \angle -69.68°}$$

$$\cong \mathbf{10 \text{ V} \angle 0°} = \frac{1}{10}(100 \text{ V} \angle 0°)$$